SOURCE LOCATION OF THE SATURNIAN KILOMETRIC RADIATION

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Abstract

The source location is one of the most important properties describing a planetary radio emission. It does not only put a constraint on the physical phenomena linked to the emission mechanism, but it gives also an idea of the acceleration regions of the particles responsible for the emission and perhaps an idea of the acceleration processes. A simple method, previously used for deriving the source location of the UKR, is here applied to Voyager's near encounter observations of SKR. It is supposed that SKR sources are fixed in latitude and local time, that the emission occurs at the cutoff frequency of the X–mode (f_x) and that the radiation can only propagate above the iso–surface $f = f_x$. The study is done over several frequencies and a very precise location is found for both northern and southern sources. They seem to be coupled with a region at high latitude near 0800 – 0900 LT on the morning side and a smaller one near 1900 LT on the evening side. This result suggests that the acceleration sources of the SKR could follow a Kelvin–Helmholtz instability arising from regions where the friction between the solar wind and the magnetosphere of Saturn is a maximum.

1 Introduction

Among the five planets in the solar system which are known to have very intense radio emissions, Saturn seems to be the best–adapted radio source for a modelling work and for a confrontation between observational data and theory because of two reasons: On the one hand the magnetosphere of the planet presents (at a first approximation) a high axial symmetry and, on the other hand, the observations obtained by the Planetary Radio Astronomy (PRA) experiment on the Voyager spacecraft constitute an homogeneous data set over several months. This leads us to consider Saturn as a starting point for the study and understanding of planetary radio emissions.

The Saturnian Kilometric Radiation (SKR) is an intense nonthermal radioelectric emission at kilometer wavelengths which originates from the high latitude regions of Saturn. Its

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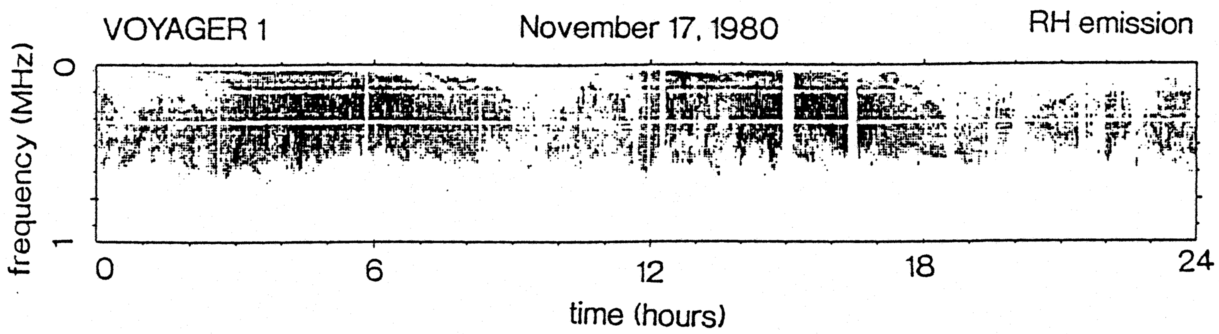

Figure 1: Dynamic spectrum of SKR.

average spectrum covers a frequency range from about 3 kHz to more than 1.2 MHz, the spectral peak is localized between 100 and 400 kHz with a flux density of about $10^{-19}\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}$ at a distance of 1 AU. The SKR is strongly polarized and is mainly emitted in the supraluminous right–handed X mode at a frequency very close to the local cutoff of this mode $f_x \simeq (1+\varepsilon)f_c$ where $\varepsilon = (f_p/f_c)^2$ is the square of the ratio of the local plasma frequency to the gyrofrequency. This radiation is linked to energetic electron precipitations within auroral regions of the planet. Figure 1 shows a dynamic spectrum of the SKR observed by Voyager 1 over 24 hours, a fews days after the encounter; the intensity of the right–handed component of the emission is displayed in a grey–shaded level on a time–frequency diagram.

2 Importance of the source location

All of the planetary radio emissions show very similar properties which leads us to assume that the same mechanism is responsible for the different radiations. The Cyclotron Maser Instability (CMI) was first proposed by Wu and Lee in [1979] for explaining the auroral kilometric radiation of the Earth. It is a relativistic resonant coupling between the electric field of a right–hand polarized wave and electrons of a magnetoplasma. This gyroresonant interaction leads to a strong amplification of the waves near the local X mode cutoff and the free energy that feeds the instability is contained in a population inversion of the electronic distribution function characterized by a positive gradient in perpendicular velocity $\partial f/\partial v_\perp > 0$. The relativistic coupling can be expressed by the relation $\omega - k_\parallel v_\parallel - \omega_c/\Gamma = 0$ (ω and $k_\parallel$ being the pulsation and parallel wave vector of the wave and $v_\parallel$ and Γ being the parallel velocity and Lorentz factor of the electron). In the case of Saturn, an inhomogeneous theory of the CMI including the gradient length of the magnetic field $L_B = |\partial(\ln B)/\partial z|^{-1}$ has to be used in order to take into account the rapid detuning of the resonance caused by the variation of B and $k_\parallel$.

Recently we computed a theoretical envelope spectrum of the SKR [Galopeau et al., 1989] based upon the CMI. This spectrum is displayed in Figure 2 and compared with the observations. This model allows to understand the typical shape of the planetary radio emission spectra and the role played by the macroscopic parameters describing the plasma in the source regions (i.e. the electronic density n_e and the magnetic field B)

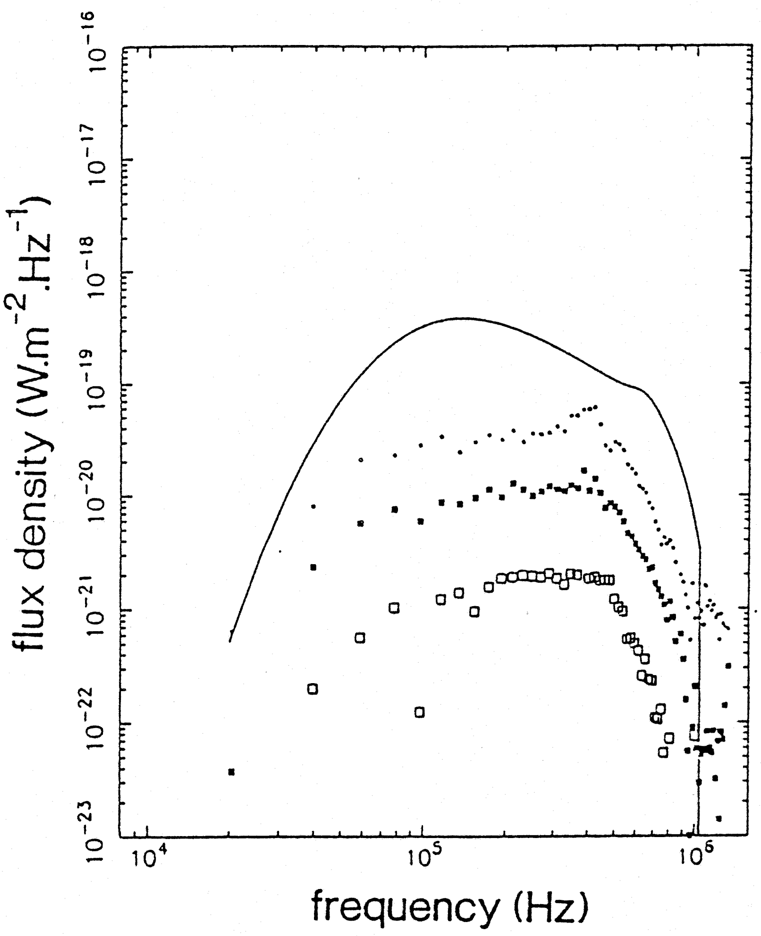

Figure 2: Theoretical envelope spectrum of SKR compared with the one observed by Voyager–PRA. The intensity reached by 50% (resp. 10%, 1%) of the events is represented by □ (resp. □, ∘).

on these spectra. Such a modelling cannot be performed without the knowledge of the above mentioned parameters. So we have to know the values that lead to the macroscopic parameters of the magnetoplasma in the source regions. Consequently, we have to know where the sources of the radiation are situated.

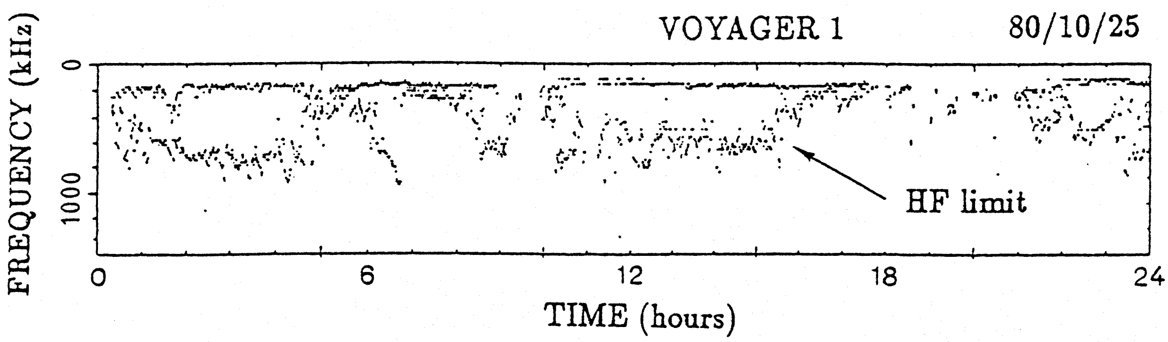

Figure 3: Low and high frequency limits of the SKR.

To a certain extent, the source location of the SKR can also play an important role in the determination of the magnetic field close to the planet. Indeed it has been shown by Galopeau et al. [1991] that the systematic study of the variation of the SKR high frequency limit as a function of the planetary rotation allows to put constraints on the magnetic field value in the high frequency source regions. In Figure 3 an example of the variation of the high frequency limit of the SKR is displayed during one day of PRA observation. Then, owing to this contribution of radio observations, it has been possible to give a first estimate and determination of Saturn's magnetic field anomaly already postulated for a long time but always kept 'invisible' to the magnetometers embarked on the different spacecraft which passed the planet too far. Galopeau et al. [1991] determined a new B–field model as an alternative to the Z_3 model obtained by Connerney et al. [1984] (from magnetometer measurements), hereafter called 'modified Z_3'. Whereas Z_3 is axially symmetric, the 'modified Z_3' presents a zone of strong intensity in the northern hemisphere explaining the modulation of the SKR during one Saturnian rotation period. This result obligatorily needs the knowledge of the source location of the radiation.

3 Source location of the radiation

The problem of the source location is a fundamental one, because it also determines the physical process that can intervene in the mechanism of the emission's generation and especially it gives an idea of the acceleration regions and thus of the acceleration processes of the particles which are responsible for this emission.

By studying the polarization of the radiation, it is possible to distinguish which part of the emission originates from the northern hemisphere and which part emanates from the southern one. As shown in Figure 4, if the radiation is produced in the X mode, the wave is right–handed relative to the local magnetic field $\vec{B}$ in the source. Because of the propagation and the geometry at the distance of the observer, the wave coming from the north appears as right–handed relatively to the wave vector $\vec{k}$ whereas the one coming from the south is left–handed with regard to $\vec{k}$.

The antennae of the PRA instrument which observed the SKR have no spatial resolution so that the determination of the source location can only be done by indirect methods. Several authors studied this problem, in particular Kaiser and Desch [1982] and Lecacheux and Genova [1983]. They found that the emission occurred along magnetic field lines which are fixed in local time, located at high latitudes on the dayside of the planet near the noon meridian. Figure 5 shows the footprints of the possible source field lines on Saturn's surface obtained by these authors for both hemispheres. The location they found for the southern source is not very accurate and the main shortcoming in Kaiser and Desch's determination lies in the fact that they had to make an a priori assumption on the beaming of the emission.

We used a different method previously developed for studying the beaming and source location of the Uranian Kilometric Radiation [Zarka and Lecacheux, 1987]. The method does not need any a priori assumption on the beaming of the emission. If the emission actually occurs in the X mode then the wave can only propagate above an altitude corresponding to the cutoff of this mode. If θ (Figure 6) is the angle between the local magnetic field $\vec{B}$ at the source and the direction of the observer (i.e. the Voyager spacecraft), then it follows that θ must be lower than 90° for the northern source and greater than 90° for

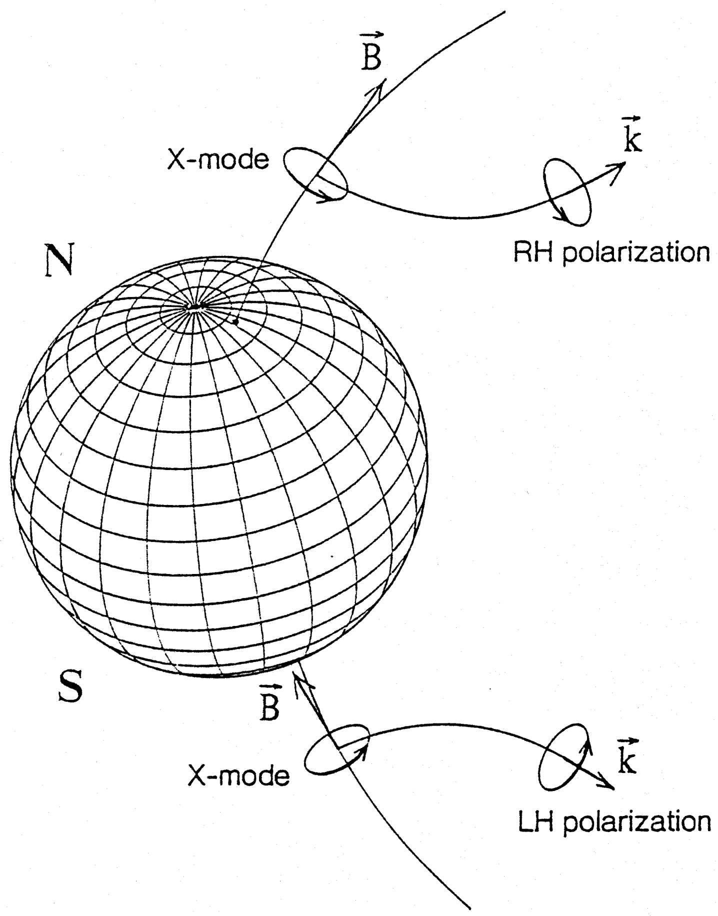

Figure 4: Polarization of the SKR for both hemispheres.

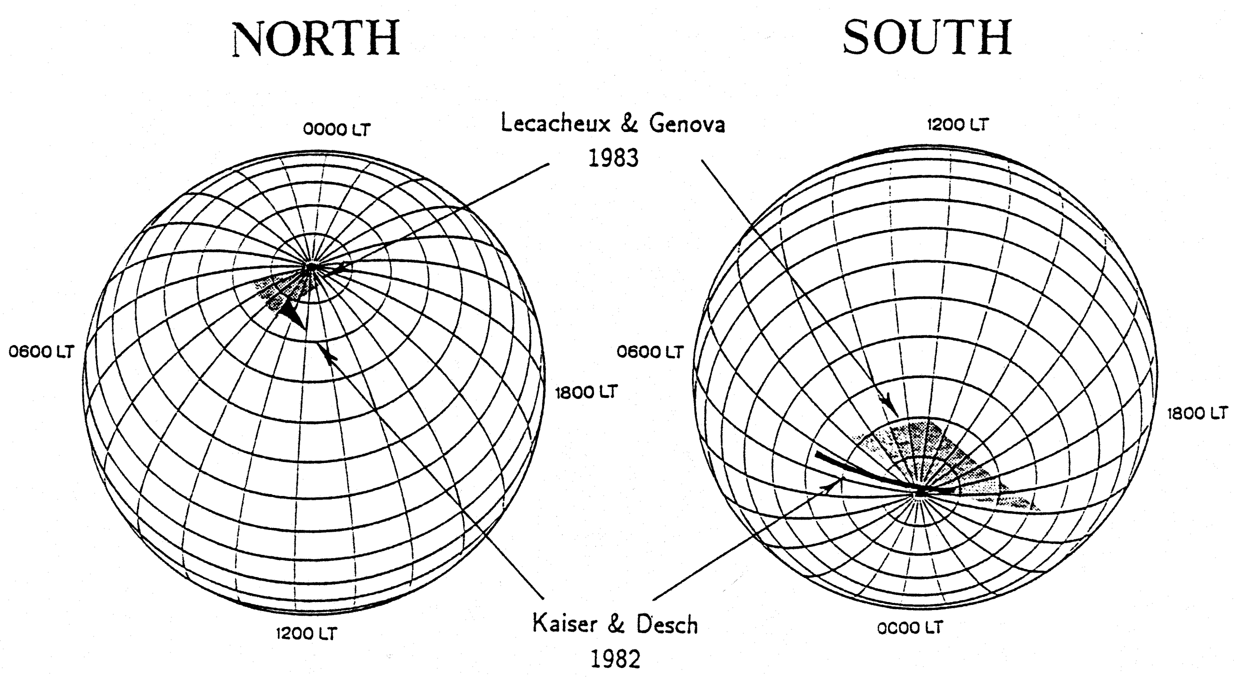

Figure 5: Source location for SKR obtained by Kaiser and Desch [1982] and by Lecacheux and Genova [1983].

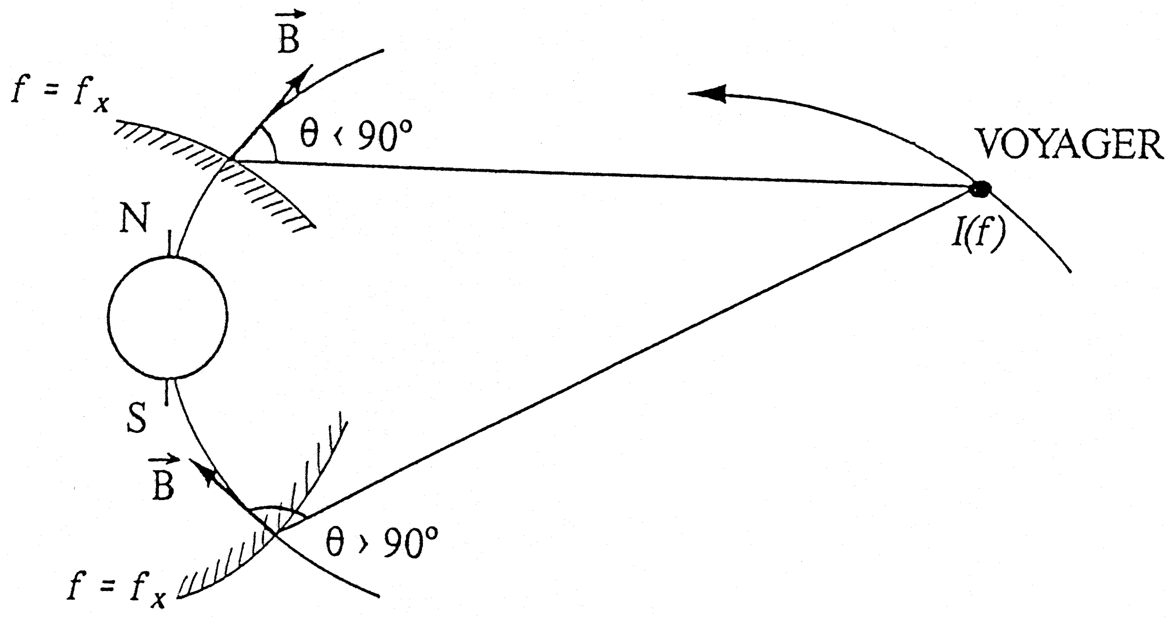

Figure 6: Geometry source–observer for both hemispheres.

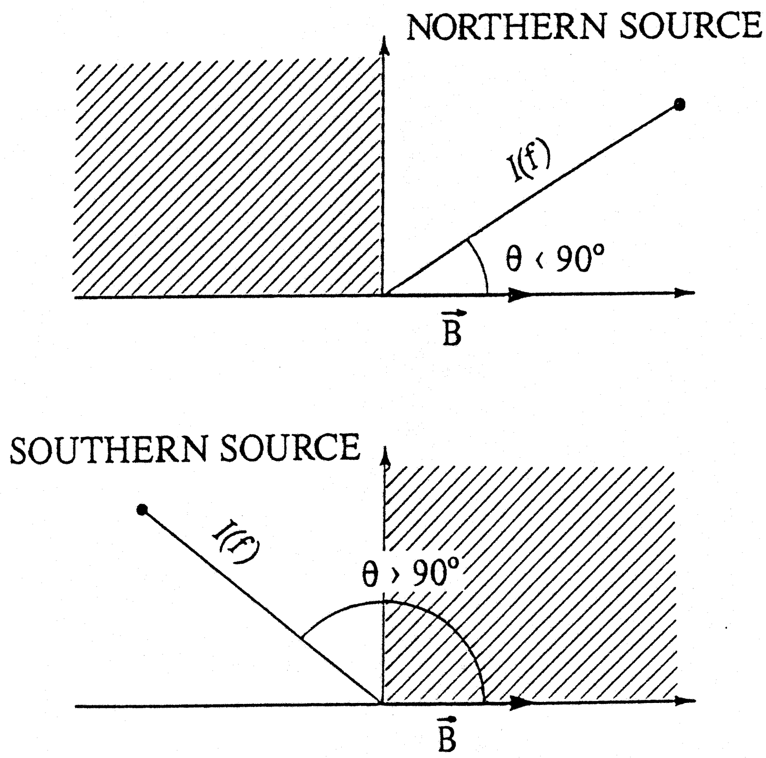

Figure 7: Position of data points for a possible source location.

the southern one. This is not a ray tracing method since the previous criterion does not depend on the individual wave path.

If we plot the intensity observed at several frequencies in both senses of circular polarization as a function of the angle θ in a polar coordinates diagram (θ, I) (Figure 7), it follows from the above statement that the possible positions (in latitude and local time) for the northern (resp. southern) source will be those for which all data points lie in the

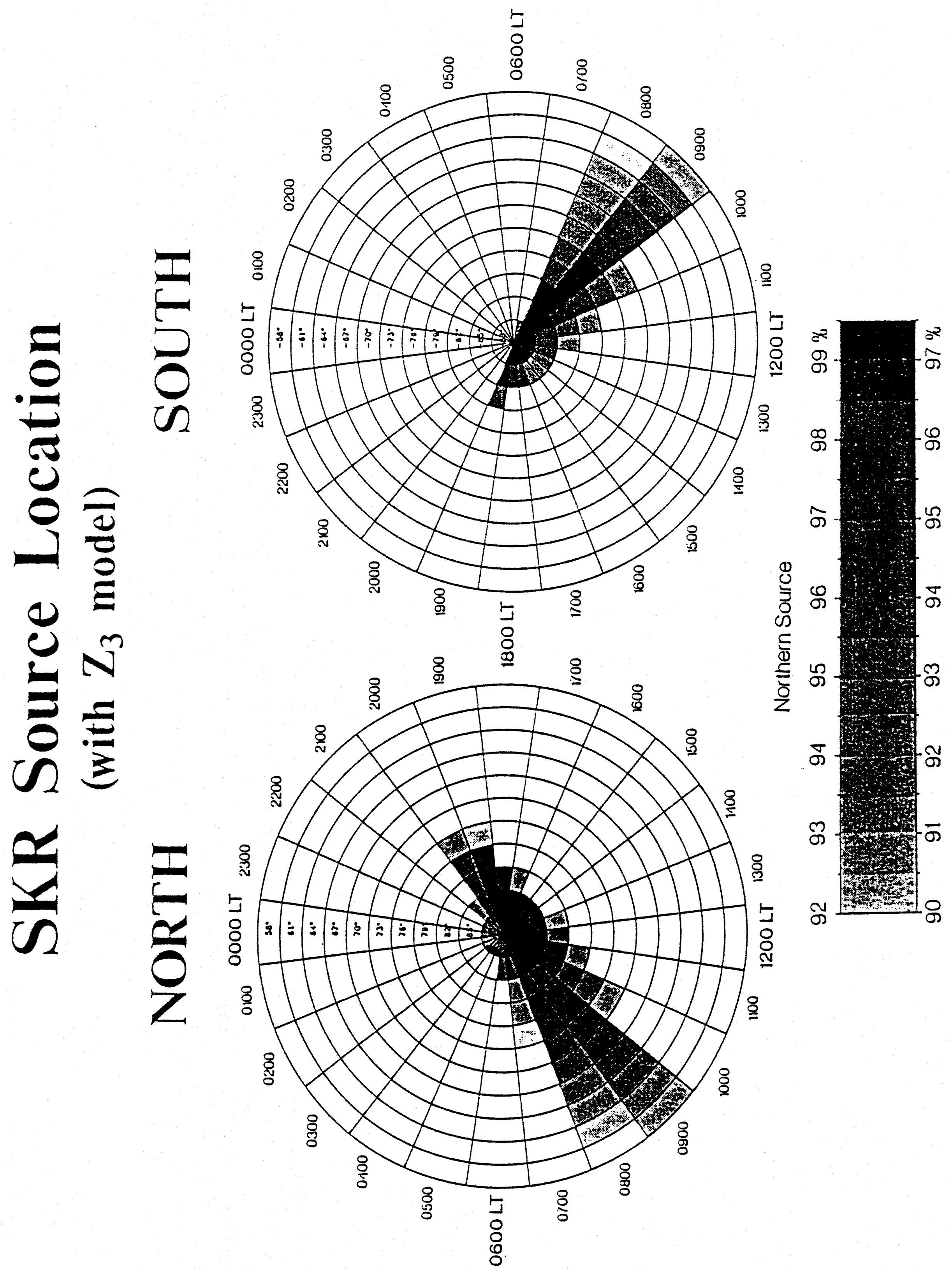

Figure 8: SKR source location with Z_3 *magnetic field model.*

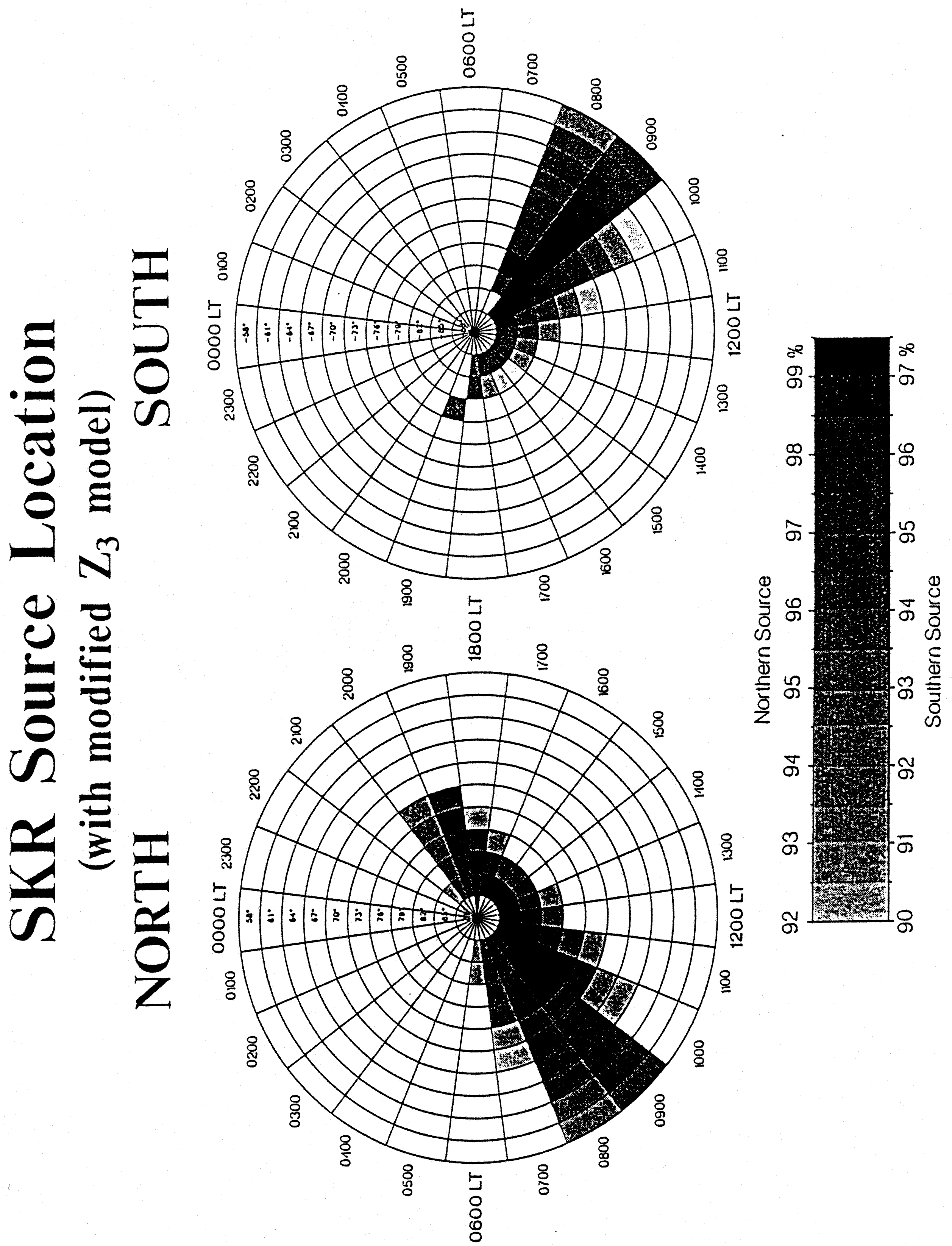

Figure 9: SKR source location with modified Z_3 *magnetic field model.*

first (resp. second) quadrant.

We have displayed in Figure 8 the percentage of the points which are in the right quadrant in a grey–shaded level for a set of test source positions in latitude and local time. This study has been done for both hemispheres and also for seven frequencies regularly spaced from 58 to 1018 kHz. We have chosen a data set covering approximately three days around each Voyager closest approach because the geometry of observation appreciably changes at those time periods. Figure 8 has been performed using the Z_3 magnetic field model of Connerney et al. [1984]. The shading zones give an idea of the probability to find the footprint of the respective source field line at the surface of Saturn. The sources essentially lie on the dayside for both hemispheres with two more additional source locations: One in the morning side at about 0800–0900 LT and a smaller one in the evening side at about 1900 LT. These sources seem to be located at the boundary of open and closed magnetic field lines. The positions obtained for North and South appear to be conjugate.

The same study was carried out on the same data but using the 'modified Z_3 model' developed by Galopeau et al. [1991]. The result is displayed in Figure 9; it does not seem to heavily depend on the chosen magnetic field model except for the polar regions at high latitude where no source is expected.

4 Conclusions

The method used in this paper leads us to the conclusion that the sources of the SKR are located at high magnetic latitudes at the boundary of open and closed magnetic field lines on the dayside. The presence of two source regions, as mentioned above (one at the morning side, one at the evening side), and the fact that the two hemispheres seem to be conjugate suggest that the source regions could be linked to zones where the friction between the solar wind and the magnetosphere is a maximum. The corotation could be responsible for the shift of the source relatively to the 0600–1800 LT line. Previous works concerning the Kelvin–Helmholtz instability at the terrestrial magnetopause [Belmont and Chanteur, 1989] indicate that such an instability could also work at Saturn and perhaps initiate SKR. This will be the aim of a future work now in progress.

This present result shows that the acceleration processes of particles responsible for the different planetary radio emissions might be widely different.

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